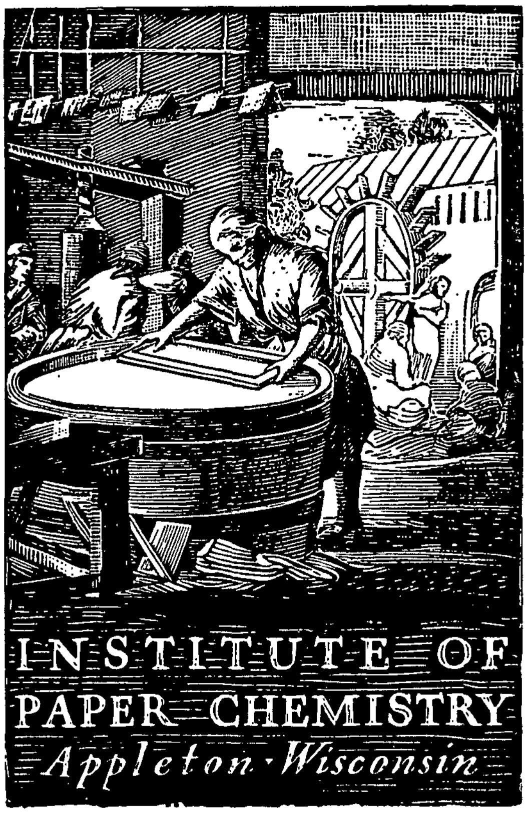
M. LORENZ

GENERAL



EFFECT OF RELATIVE HUMIDITY AND TEMPERATURE ON STACKING PERFORMANCE

Project 2695-9

Report One

A Summary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

November 10, 1972

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

This study was initiated for the purpose of studying the effect of R.H. and temperature on the (a) stacking (creep) behavior of individual and stacked corrugated boxes and (b) combined board edgewise compression creep behavior. Two C-flute box samples made from 200- and 350-lb. series combined board were tested at the following conditions: (1) 50% R.H., 73°F. (standard conditions); (2) 85% R.H., 73°F.; and (3) 90% R.H., 90°F.

The stacking tests on the boxes were carried out using two procedures. In the first procedure, dead loads were applied to individual boxes and the time to box failure was observed. These are termed individual box stacking tests. In the second procedure, dead loads were applied to stacked boxes (5 boxes per tier, 4 tiers high) and the times to attain selected deflection levels were recorded.

The following results were obtained:

BOX RESULTS

1. At a given load ratio the results for both the individual and stacked boxes indicated that failure times significantly increased as the test atmosphere changed from 90% R.H., 90°F., to 85% R.H., 73°F. to 50% R.H., 73°F. Conversely, for a given stacking time the load ratio increased as the test atmospheres were changed in the same order. This indicates that box stacking load is affected to a

greater extent by the ambient atmosphere than is the short-term compression strength of the box or stacked boxes.

2. Average estimated load ratios in the three atmospheres are shown below for a 180-day storage period. Similar results are given in the text for 90 and 360-day periods.

Condition	Load Ratio (180 Day) Individual Boxes	Stacked Boxes
50% R.H., 73°F.	0.562	0.672
85% R.H., 73°F.	0.376	0.469
90% R.H., 90°F.	0.305	0.410

As may be noted, the load ratio decreases rapidly as the R.H. in the test atmosphere increases for both individual and stacked boxes. It also may be noted that the higher load ratios were obtained for the stacked boxes. While this may be due to test variability, it may indicate that stacked boxes behave somewhat differently than the individually tested boxes. This point may warrant further investigation.

3. The applied loads, expressed as a percentage of the box strength at standard conditions, varied exponentially with the moisture content of the combined board (neglecting any temperature effects). The following results were calculated for a 180-day storage period; values are given in the text for 90 and 360-day periods.

Moisture Content, %	Load in Percentage of Strength at Standard Conditions (180 Day) Individual Boxes	Stacked Boxes
7.5	55	67
10.0	40	50
12.5	29	37
15.0	21	27
17.5	15	20
20.0	11	15

The results indicate that the allowable load decreases very rapidly with increased moisture content. For this reason overdesign of a package to meet environmental conditions which are rarely encountered can be costly.

4. It should be noted that the boxes were fabricated from combined boards made with regular starch adhesive. It was observed that there was a tendency for the adhesion to fail at 90% R.H., 90°F. as exposure times increased. This probably would not occur if weather-resistant adhesive were used and, hence, high moisture contents might have a lesser effect on the stacking behavior if weather-resistant adhesive were used. This warrants further study.

EDGEWISE COMPRESSION RESULTS

1. The creep results for the edgewise compression tests exhibited the same trends as the box results, i.e.,

the compression creep behavior of the combined board was affected more by moisture content than the short-term compression strength.

2. When the applied load, expressed in percent of the short-term strength at standard conditions, was related to moisture content the following results were obtained.

Moisture Content, % o.d.	180-Day Load, in percentage of strength at standard conditions
7.5	48
10.0	37
15.0	23
20.0	14

Thus, the percentage loads were roughly about the same as were obtained for the individually tested boxes and decreased rapidly as moisture content increased.

INTRODUCTION

One of the major factors affecting the stacking (creep) performance of corrugated containers is the moisture content of the board. The equilibrium moisture content is dependent on the ambient temperature and R.H. among other factors. It is well known that a corrugated box loses 50-60% or more of its short-term top load box compression strength when the R.H. is increased from 50 to 90% R.H. There is much less information in the literature relative to the stacking performance of boxes and combined board at various moisture content levels.

Accordingly, this study was initiated for the purpose of studying the effect of R.H. and temperature on the (a) stacking (creep) behavior of individual and palletized boxes, and (b) combined board short column stacking (creep) behavior.

In the literature, Kellicut and Landt (1) have indicated that, at constant load ratio, moisture content does not affect stacking life. Load ratio in this case is defined as the ratio of the applied load to the short-term box compression strength in the test atmosphere. Moody and Skidmore (2) also reported that, at constant load ratios, box failure times were about the same at 65% R.H., 80°F. as at standard conditions (50% R.H., 73°F.).

Stott (3) studied stacking strength at four moisture content levels, namely, 5.5, 10.0, 13.5, and 19.2%. Figure 1, taken from his paper, shows the relationships between load (in percentage of average compression strength) and survival time. As moisture content increased, the levels of the load vs. survival time lines decreased significantly. The ordinate in Fig. 1 is the same as Kellicutt's load ratio but expressed in percentage. Inasmuch as the loads are referenced to the box compression strength at the same moisture content, Stott's results show that moisture has a greater effect on stacking strength than on compression strength. Stott also graphed the load for 200 day's survival time (expressed in percentage of the compression strength at 10% moisture) as a function of moisture content. This graph (Fig. 2) shows that the 200-day load decreases very rapidly with increased moisture content. Stott commented that "the stacking strength at 10% moisture is approximately twice that at 17.5%.

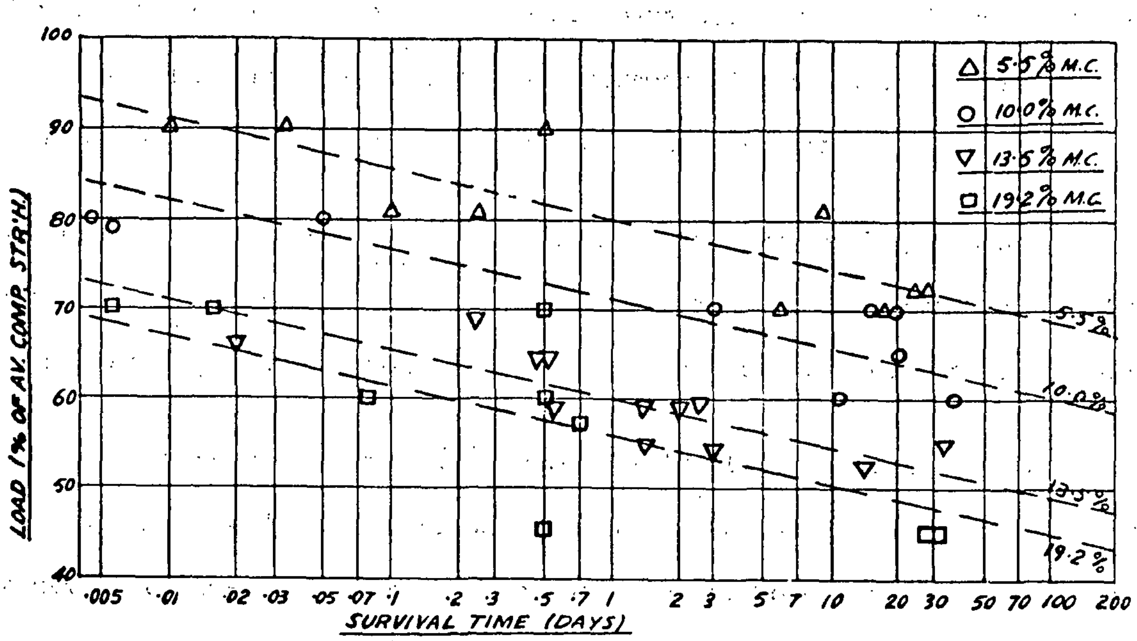

Figure 1. Percentage Applied Load vs. Survival Time at Various Moisture Contents [Stott (3)]

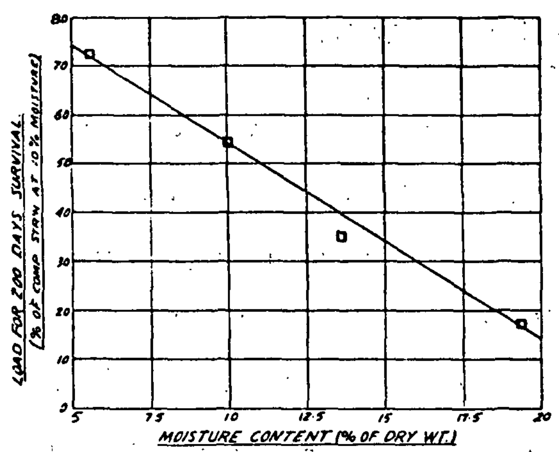

Figure 2. Effect of Moisture Content on 200-Day Stacking Load in Percentage of Box Compression Strength at 10% Moisture [Stott (3)]

In a past study for F.K.I., a limited comparison indicated that both boxes and combined board columns exhibited substantially shorter lives at 90% R.H. as compared to 50% R.H., both at the same load ratio (4). This result is in qualitative agreement with Stott's findings.

Greenway (5) compared stacking lives at 85% R.H., 85°F. and 50% R.H., 73°F. using three high stacks. His tests were carried out at high load levels; consequently, the failure times were very short — no more than 0.014 day on the average at 85% R.H. Higher rates of creep were obtained at the high R.H. temperature condition for these very short time intervals. If Greenway's results were extrapolated to longer time intervals — which may be hazardous — they would also be in qualitative agreement with Stott's work.

It is apparent from the above that the evidence in the literature as to the effect of moisture on stacking performance is contradictory.

In all of the above, the R.H. and temperature were held constant during the testing. However, in most warehouse environments both the R.H. and temperature fluctuate from day-to-day. No stacking (creep) tests have been carried out on corrugated boxes exposed to cyclic fluctuations in R.H. or temperature. However, Byrd (6) recently carried out tensile creep tests on handsheets during which the R.H. was alternately cycled between 35 and 90%. Among other things, he reported that rupture life decreased under cyclic conditions as compared to creep at constant moisture content. It appears probable that a similar result would occur in stacking tests on boxes.

MATERIALS

Two C-flute box samples made from (a) 200-lb. and (b) 350-lb. series combined board were obtained for this study. They are identified as Sample C-200 and Sample C-350 in this report. Regular starch adhesive was used in fabricating the boxes. The box size was 20-1/4 x 13-1/2 x 12-1/2 inches. Both box samples were made with a glued manufacturer's joint. Nine cell partitions, made from 200-lb. series board, were also procured but were not used for the stacking tests because the compression results on the boxes with partitions tended to exhibit high variability.

TEST ATMOSPHERES

1. 50 ± 2% R.H., 73°F.
2. 85 ± 2% R.H., 73°F.
3. 90 ± 2% R.H., 90°F.

CONDITIONING

All materials were preconditioned for at least 24 hours at less than 35% R.H. and 73°F. For tests at 50% R.H., the boxes and combined board samples cut from the boxes were conditioned at least 48 hours prior to test; at 85 and 90% R.H., the boxes and combined board samples were conditioned at least 120 hours prior to test.

BOX CLOSURE

The bottom closure in all boxes was made with staples. For boxes which were to be tested individually for either short-term compression strength or stacking performance, the top flaps were sealed using silicate adhesive at 50% R.H. and Dupont 77 for the boxes to be tested at 85 or 90% R.H.

For the C-200 boxes which were tested in palletized arrays, hot melt adhesive was used to make the top closure so as to avoid having sealing boards in the boxes during test.

TEST PROCEDURES

BOX COMPRESSION TESTS

For each sample, ten boxes were evaluated for top load compression strength in each atmosphere.

For the C-200 box sample, compression tests were also carried out on stacked boxes. The stacking pattern employed is shown in Fig. 3. There were 5 boxes in a tier, and the stack was 4 tiers high. The compression tests were carried out in a Baldwin Southwark Universal tester at a test rate of 0.5 in./minute. A photograph of one of the stacked arrays in the tester is shown in Fig. 4. In the case of the tests on boxes conditioned at 85 or 90% R.H., the stacks were assembled in the conditioned atmosphere. They were then shrouded in polyethylene, transported to the Baldwin tester, and tested as quickly as possible.

BOX STACKING (CREEP) TESTS

The creep tests on the C-200 and C-350 boxes tested individually were carried out using the equipment described in Reference (7). In general, four boxes per sample were tested at each of four load levels in each atmosphere. The load levels were selected in so far as possible to give failure times no longer than 60-90 days.

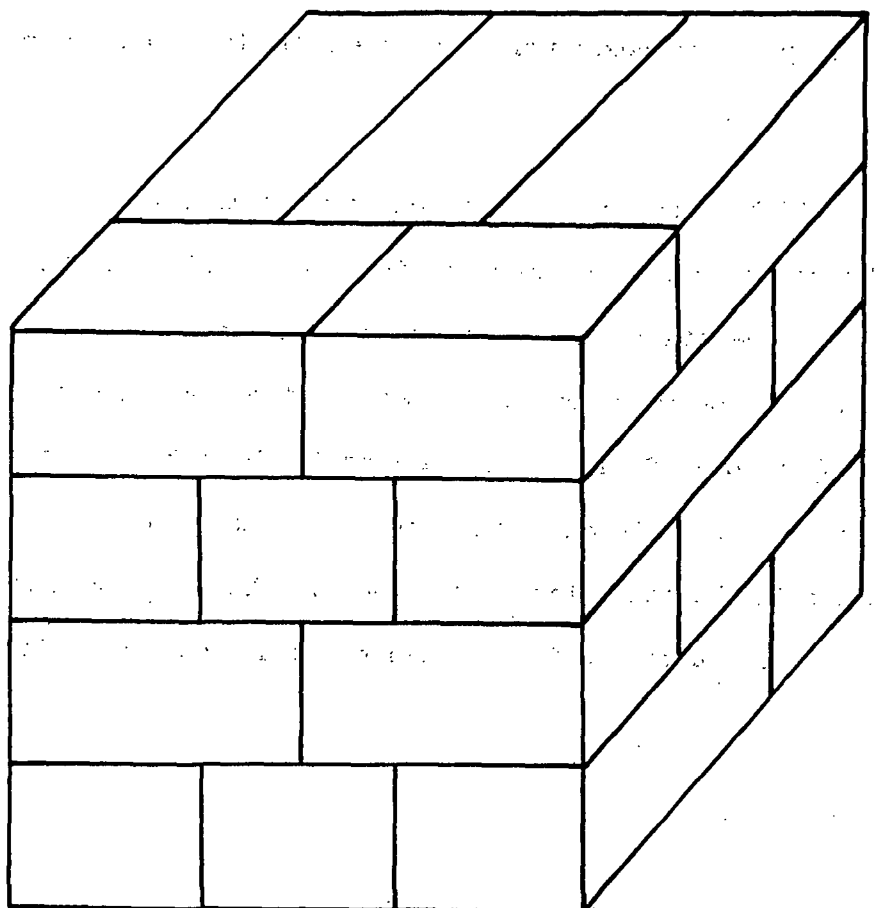

Figure 3. Stacking Pattern for Stacked C-200 Boxes

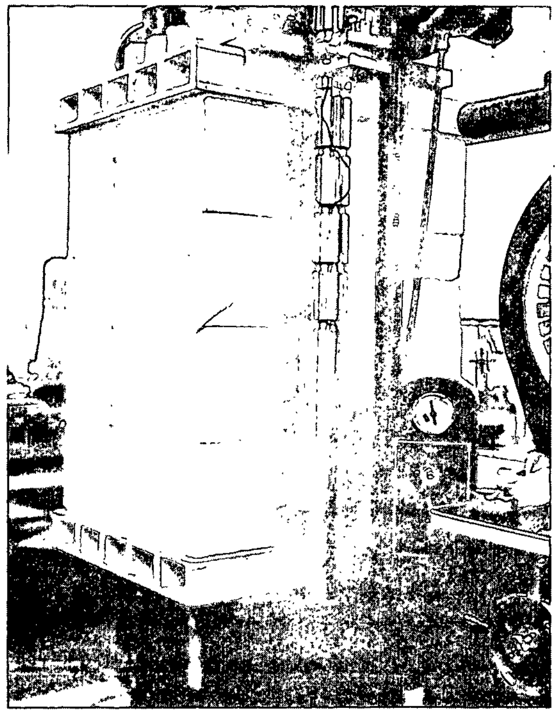

Figure 4. Appearance of Stacked Boxes in Compression Tester

The creep tests on the stacked boxes were carried out using the apparatus shown in Fig. 5. Load was applied by means of a pressurized hydraulic cylinder attached to the top of the frame at 50 and 85% R.H. However, at 90% R.H., 90°F. dead weights were used to apply the load because of the low load levels involved. The central deflection of the stacks was measured using a depth micrometer. In general, two stacks were tested at each of three or four load levels in each atmosphere. The load levels were selected in so far as possible to give failure times no longer than 60-90 days. Inasmuch as stacks do not collapse as occurs in the case of the creep tests in individual boxes, the end point of the stack tests was taken as the time when the central deflection reached the average deflection level at which maximum load was attained in the short-term stack compression tests.

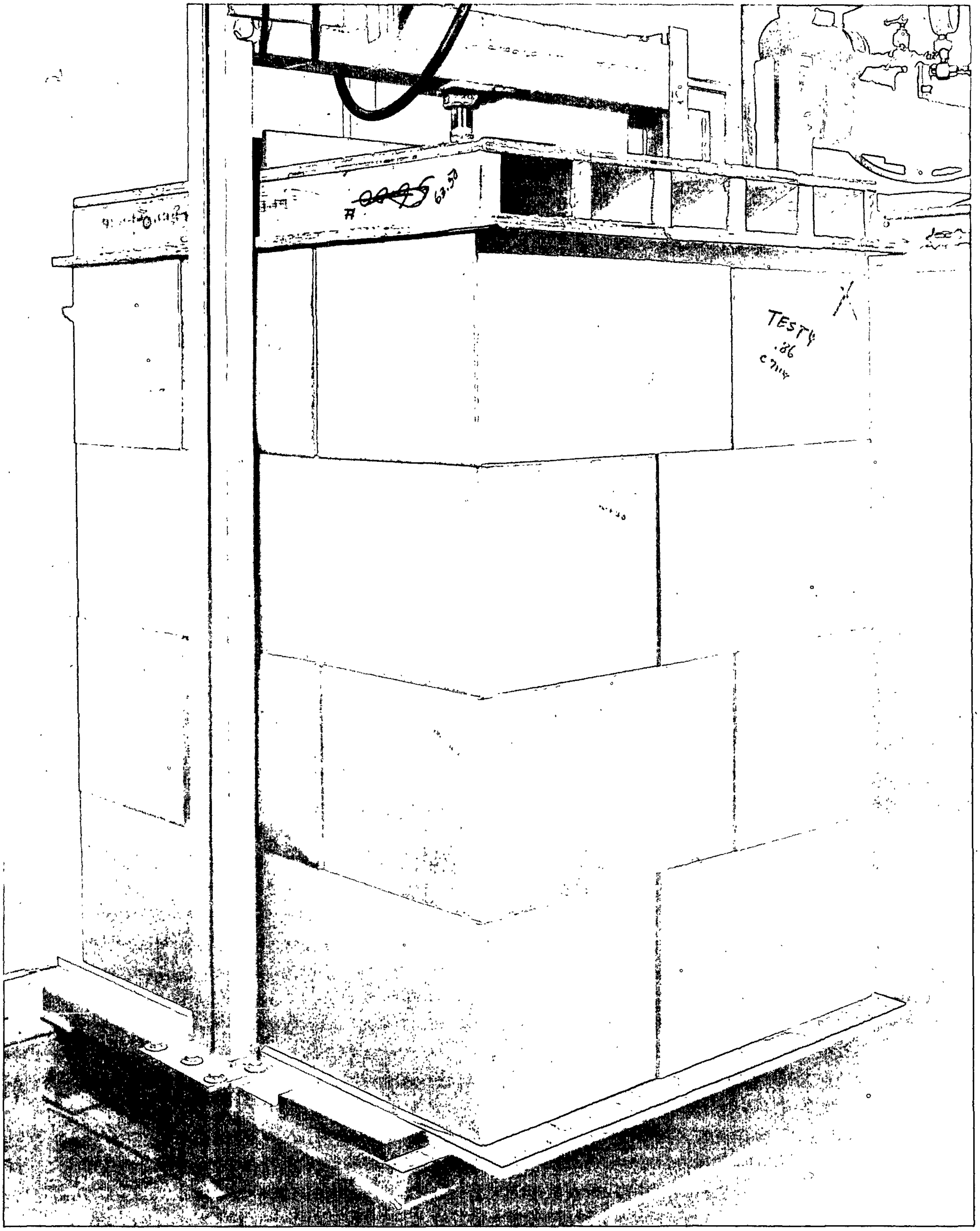

Figure 5. Appearance of Stacked Boxes in Creep Tester

COMBINED BOARD TESTS

The C.D. edgewise compression creep tests were carried out using 2 x 2 x 1.25-inch rectangular specimens with wax reinforced edges. They were tested using essentially the same apparatus as was used for the stacking tests on the individual boxes. In general, four tests/sample were carried out at each of four load levels in each atmosphere.

In addition, to characterize the materials, the following tests were carried out on each sample in each atmosphere:

1. Caliper
2. C.D. edgewise compression (rectangular 2 x 2 x 1.25-inch specimen)
3. Flexural stiffness (50% R.H. only)
4. Pin adhesion
5. Moisture content
6. Basis weight (50% R.H. only).

DISCUSSION OF RESULTS

BOX COMPRESSION RESULTS

Top load box compression tests were carried out on both empty boxes and boxes with nine cell partitions because it was originally planned to conduct the stacking tests on boxes with partitions. The box compression results are summarized in Table I. At 85% R.H., 73°F. the maximum loads for the empty boxes were 34.5 and 38.6 lower than at standard conditions for Samples C-200 and C-350, respectively; at 90% R.H., 90°F. the reductions in strength were 66.6 and 55.8% for the two samples.

The empty boxes gave coefficients of variation of 5.3 and 6.8% at standard conditions for the C-200 and C-350 samples, respectively. The corresponding coefficients of variation for the boxes tested with partitions were 3.5 and 18.0%. Thus, the C-350 boxes with partitions exhibited a high variability. This was caused by box-to-box differences in the way the panels bowed during the test. If the panels bowed against the partition higher test results were obtained than if the opposite occurred. This effect did not occur in the case of the C-200 boxes with partitions because the panel walls bowed outwards in all cases.

At standard conditions, the C-200 boxes with partitions gave loads which were 65.4% greater than the empty boxes. In the case of the C-350 boxes, the presence of the partition resulted in an 82.4% increase. The difference in percent improvement due to the partition is probably related to the panel bowing effect noted above.

TABLE I

TOP LOAD BOX COMPRESSION RESULTS

Sample Code	Property	50% R.H., 73°F.	85% R.H., 73°F.	Diff., %[a]	90% R.H., 90°F.	Diff., %[a]
		Empty Boxes				
C-200	Max. load, lb.	864	566	-34.5	289	-66.6
	Coeff. of variation	5.3	6.5	--	--	--
	Max. defl., in.	0.55	0.51	-7.3	0.44	-20.0
	Moisture content, % o.d.	7.5	13.8	--	21.2	--
C-350	Max. load, lb.	1342	824	-38.6	593	-55.8
	Coeff. of variation	6.8	7.2	--	--	--
	Max. defl., in.	0.56	0.55	-1.8	0.54	-3.6
	Moisture content, % o.d.	7.0	14.6	--	20.7	--
		Boxes with Nine Cell Partitions				
C-200	Max. load, lb.	1429	927	-35.1	--	--
	Coeff. of variation	3.5	6.0	--	--	--
C-350	Max. load, lb.	2448	1451	-40.7	--	--
	Coeff. of variation	18.0	10.5	--	--	--

[a]Based on results at standard conditions as reference.

It was originally planned to conduct the stacking tests on boxes with partitions. Also, it was suggested that box samples exhibiting coefficients of variation greater than 6.5% at standard conditions should not be used for stacking tests because the variability in stacking tests would be excessive. On the basis of these results it appeared that the empty box compression results approximately met the 6.5% criterion. On the other hand, it appeared that the C-350 boxes with partitions exhibited such high variability as to make them unsuitable for stacking tests. Therefore, it was decided to carry out all the stacking tests using empty boxes.

Compression tests were also carried out in stacked arrays of the C-200 boxes. An interlocking pattern with five boxes in a tier, four tiers high, was employed as shown in Fig. 3 and 4. The compression results are summarized in Table II. On a per box basis, the stacked boxes exhibited an average load of 365 lb. at standard conditions. This is 57.8% less than the average load of 864 lb. obtained for the C-200 boxes tested individually. At 85% R.H., 73°F. and 90% R.H., 90°F., the percentage reductions in load relative to the individual box tests were 54.6 and 59.9%, respectively. These reductions in strength occur because the load bearing elements (box panel walls in this case) are not aligned so as to fully utilize the compressive potential of the element. It is evident that the stacking pattern can significantly affect the compression efficiency. As a result, it is sometimes possible to obtain marked improvements in stacking performance by proper design of the box and inner packing in relation to the stacking pattern.

In so far as the effect of moisture content is concerned, the stack loads decreased with moisture content at approximately the same rate as the loads for the individually tested boxes. Average load-deflection curves for the stack compression tests in the three atmospheres are shown in Fig. 6.

TABLE II

COMPRESSION RESULTS ON STACKED BOXES

(Sample C-200)

Condition	Maximum Load, lb. Total	Load per Box[c]	Stack Deflection, in. From Zero Load	From 250 Lb.[b]
50% R.H., 73°F.	1824	365	1.92	1.53
85% R.H., 73°F.	1283	257	1.82	1.38
Diff., %[a]	-29.7	-29.7	-5.2	-9.8
90% R.H., 90°F.	581	116	1.37	0.76
Diff., %[a]	-68.1	-68.1	-28.6	-50.3

[a]Based on 50% R.H., 73°F. results as reference.
[b]Based on zero deflection at 250-lb. preload (5 boxes per tier times 50 lb.).
[c]Total stack load divided by number of boxes per tier (5).

BOX STACKING RESULTS

The average box stacking results are summarized in Table III, while the individual test results are shown in Appendix I. Figure 7 shows that the applied load which a box will support for a given time markedly decreases as the test atmosphere is changed from 50 to 85 to 90% R.H. This would be expected because of the effect of moisture content on box compression strength.

In Fig. 8, load ratio vs. failure time curves are shown where load ratio is defined as the ratio of the applied load to the box compression strength in the test atmosphere. It may be noted that, at a given load ratio, the failure times markedly increase as the test atmosphere is changed from 90% R.H., 90°F.,

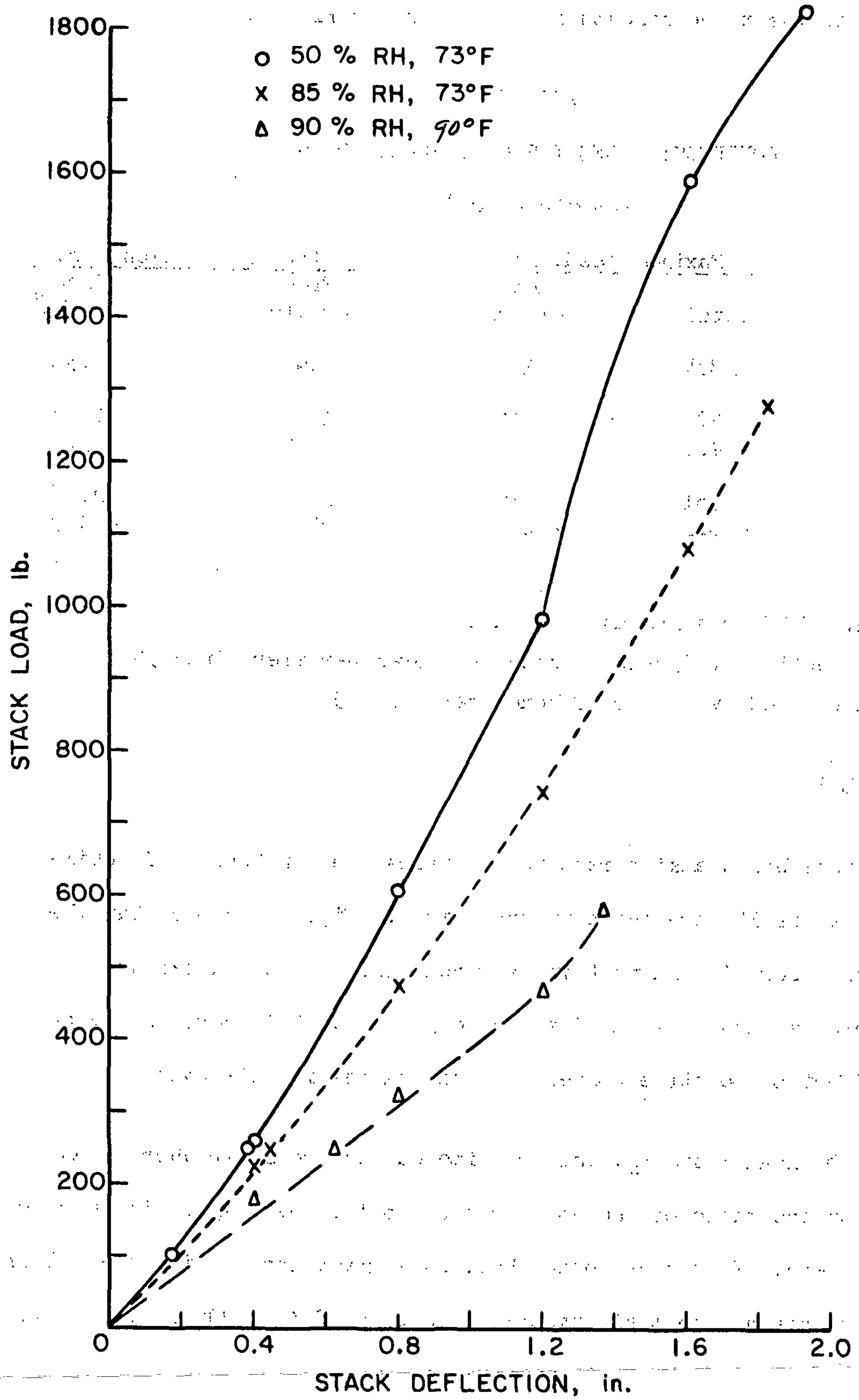

Figure 6. Average Load-Deflection Curves for Stacked Boxes

TABLE III

AVERAGE BOX STACKING RESULTS

Load Ratio[a]	Sample C-200						Sample C-350					
	50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.		50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.	
	P_a, lb.	t, day	P_a, lb.	t, day	P_a, lb.	t, day	P_a, lb.	t, day	P_a, lb.	t, day	P_a, lb.	t, day
0.74	639	1.71	419	0.013	--	--	993	0.64	610	0.123	--	--
0.70	605	3.07	396	0.022	--	--	939	3.01	577	0.80	--	--
0.66	570	11.6	374	0.174	--	--	886	6.14	544	1.16	--	--
0.62	536	36.3	351	0.46	--	--	832	38.7	511	4.66	--	--
0.54	--	--	306	3.08	156	0.85	--	--	445	7.28	320	0.57
0.50	--	--	283	10.5	--	--	--	--	412	19.9	296	3.66
0.42	--	--	238	60.7	121	8.5	--	--	346	46.8	249	18.1
0.38	--	--	--	--	110	20.6	--	--	--	--	--	--

[a]Ratio of applied load to box compression strength in the test atmosphere.

Note: P_a is the **applied** load and t is the failure time.

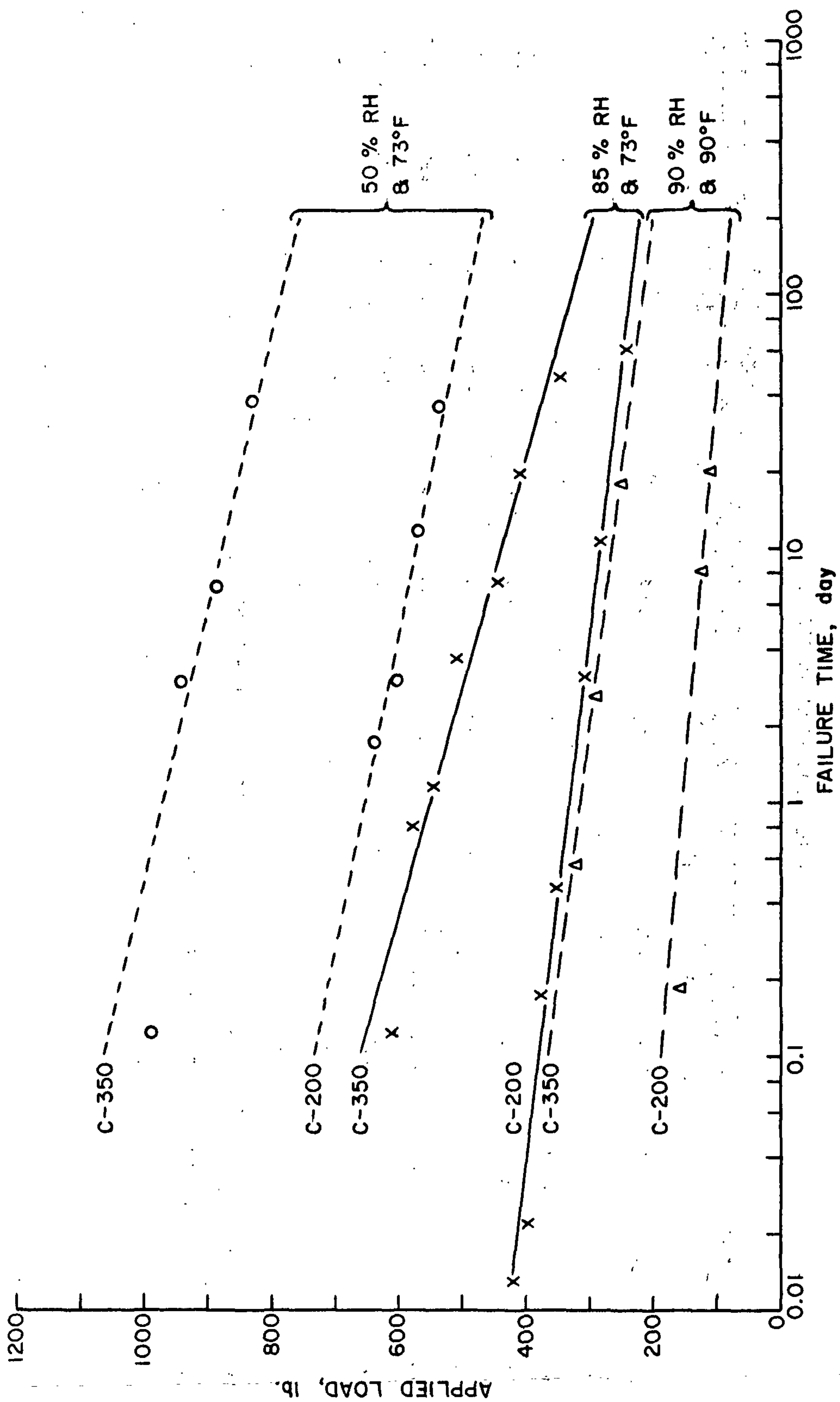

Figure 7. Load vs. Failure Time Curves for Boxes

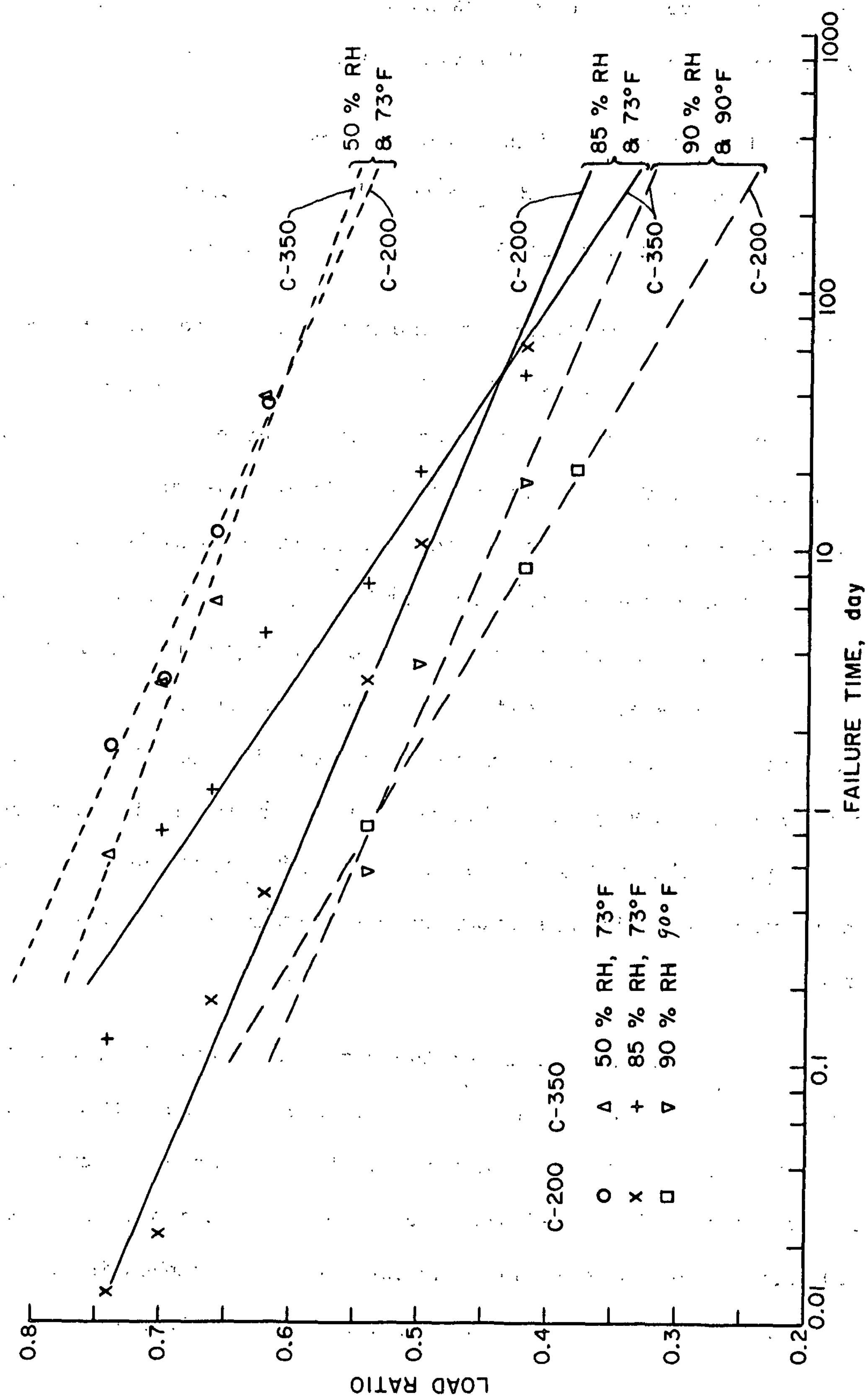

Figure 8. Load Ratio vs. Failure Time Curves for Boxes

to 85% R.H., 73°F., to 50% R.H., 73°F. An analysis of covariance indicated that the differences in level of the regression lines due to test atmosphere were highly significant (beyond the 0.01 level) for both samples.

Thus, these results exhibit the same trends as were obtained by Stott (3). They do not confirm Kellicutt and Landt's (1) conclusion that failure time is constant at a given load ratio for different R.H. levels.

The differences in "level" of the regression lines between 50 and 85% R.H. (both at 73°F.) can be attributed to the increase in moisture content as R.H. is increased, i.e., apparently creep rates increase as moisture content increases. In the main, the same explanation holds for the 90% R.H., 90°F. results as a substantial increase in moisture content occurs as R.H. is increased from 85 to 90%. Increasing the temperature from 73 to 90°F. could have two effects. First, at a given R.H., moisture content decreases very slightly as the temperature increases. It is believed this effect would be of minor importance in this case. Second, temperature affects most properties of materials and it seems possible that higher creep rates might be obtained as the temperature is increased. However, it appears likely that the effect of a 17°F. difference in temperature is probably overshadowed in this study by the moisture content changes due to R.H. changes.

The regression constants for the regression lines illustrated in Fig. 8 are tabulated in Table IV. Fairly large differences in slope were obtained but they did not vary in a regular pattern as the test atmosphere changed. However, analysis of covariance indicated that the differences in slope were significant at the 0.01 level. For this reason, the data were not graphed in Fig. 8 as a family of parallel lines, although the regression constants for this situation

TABLE IV

REGRESSION CONSTANTS FOR RELATIONSHIPS BETWEEN LOAD RATIO AND FAILURE TIME FOR BOXES

Sample No.	Conditions		Moisture Content, %	Individual Regression Lines						Parallel Line Fit				
	R.H., %	Temp., °F.		Slope, b[a]	Intercept, Log a	Corr. Coeff.	Predicted Load Ratio 90 Day	180 Day	360 Day	Slope, b	Intercept, Log a	Predicted Load Ratio 90 Day	180 Day	360 Day
C-200	50	73	7.5	-11.40	8.5894	0.989	0.582	0.556	0.529	-9.89	7.5617	0.567	0.537	0.506
	85	73	13.8	-11.80	6.8503	0.994	0.415	0.390	0.364	-9.89	5.7130	0.380	0.350	0.319
	90	90	21.2	-8.57	4.5536	0.999	0.303	0.268	0.233	-9.89	5.1411	0.322	0.292	0.261
C-350	50	73	7.0	-14.13	10.2767	0.987	0.589	0.567	0.546	-9.89	7.3903	0.550	0.519	0.489
	85	73	14.6	-7.44	4.9522	0.968	0.403	0.362	0.322	-9.89	6.4139	0.451	0.420	0.390
	90	90	20.7	-11.95	6.3432	0.972	0.367	0.342	0.317	-9.89	5.3384	0.342	0.312	0.281

[a]Differences in slope were statistically significant at the 0.01 level.

Note: Regression equation form: Log $\underline{t}$ = Log $\underline{a}$ + $\underline{bR}$ where $\underline{t}$ is the failure time in days, $\underline{R}$ is the load ratio, and $\underline{a}$, $\underline{b}$ are regression constants.

are also shown in Table IV. Stott (3) found no statistical difference in slope as moisture content changed. This is not regarded as a major point of difference because creep failure times are highly variable. With limited, highly variable data the slope values are not known very exactly, i.e., they have wide confidence limits. Hence, as Stott mentioned, instead of being parallel as moisture content changes, "the actual relationships could be a series of shallow curves or converging lines, but that this would be detected only by a much greater number of tests."

Table IV also shows the load ratios corresponding to extrapolated failure times of 90, 180, and 360 days. Table V shows the average results for the two samples.

TABLE V

EFFECT OF TEST ATMOSPHERE IN LOAD RATIOS
FOR VARIOUS TIME PERIODS

Condition	Average Load Ratio		
	90-Day Life	180-Day Life	360-Day Life
50% R.H., 73°F.	0.586	0.562	0.538
85% R.H., 73°F.	0.409	0.376	0.343
90% R.H., 90°F.	0.335	0.305	0.275

Thus, at 50% R.H., the average load ratio corresponding to a 180-day life was 0.562; this declined to 0.376 at 85% R.H., 73°F. and to 0.305 at 90% R.H., 90°F. These decreases are very substantial — particularly when it is kept in mind that top load compression strength also decreases markedly with moisture content. On the average, at 50% R.H. the load supported for 180 days would be 486 lb. (0.562 x 864 lb.) for Sample C-200. At 90% R.H., 90°F., the load supported for 180 days would be only 88 lb (0.305 x 289 lb.) for Sample C-200. This is a loss in load-supporting capacity of 82%, whereas the loss in short-term compression strength was only 66.6%.

The ratios for 90, 180, and 360-day life are plotted vs. moisture content in Fig. 9. Parallel straight lines were fitted to the data for 90, 180, and 360-day failure times. The regression equation was as follows:

$$\text{Log } R = -0.01988m - k \qquad (1)$$

where

R = load ratio

m = moisture content, % o.d.

k = -0.0850 at 90-day life; -0.1173 at 180-day life, and -0.1528 at 360-day life

Thus, neglecting any temperature effect the load ratio for a given survival time decreases rapidly with increased moisture content as shown in Fig. 9. The following values were read from Fig. 9:

Moisture, %	Load Ratio 90-Day Life	180-Day Life	260-Day Life
7.5	0.58	0.54	0.50
10.0	0.52	0.49	0.45
12.5	0.46	0.43	0.40
15.0	0.41	0.39	0.36
17.5	0.37	0.35	0.32
20.0	0.33	0.31	0.29

Because the compression strength at other R.H. levels is frequently not known, it is also convenient to convert the load ratios to load as a percentage of the box compression strength at standard conditions. The results are

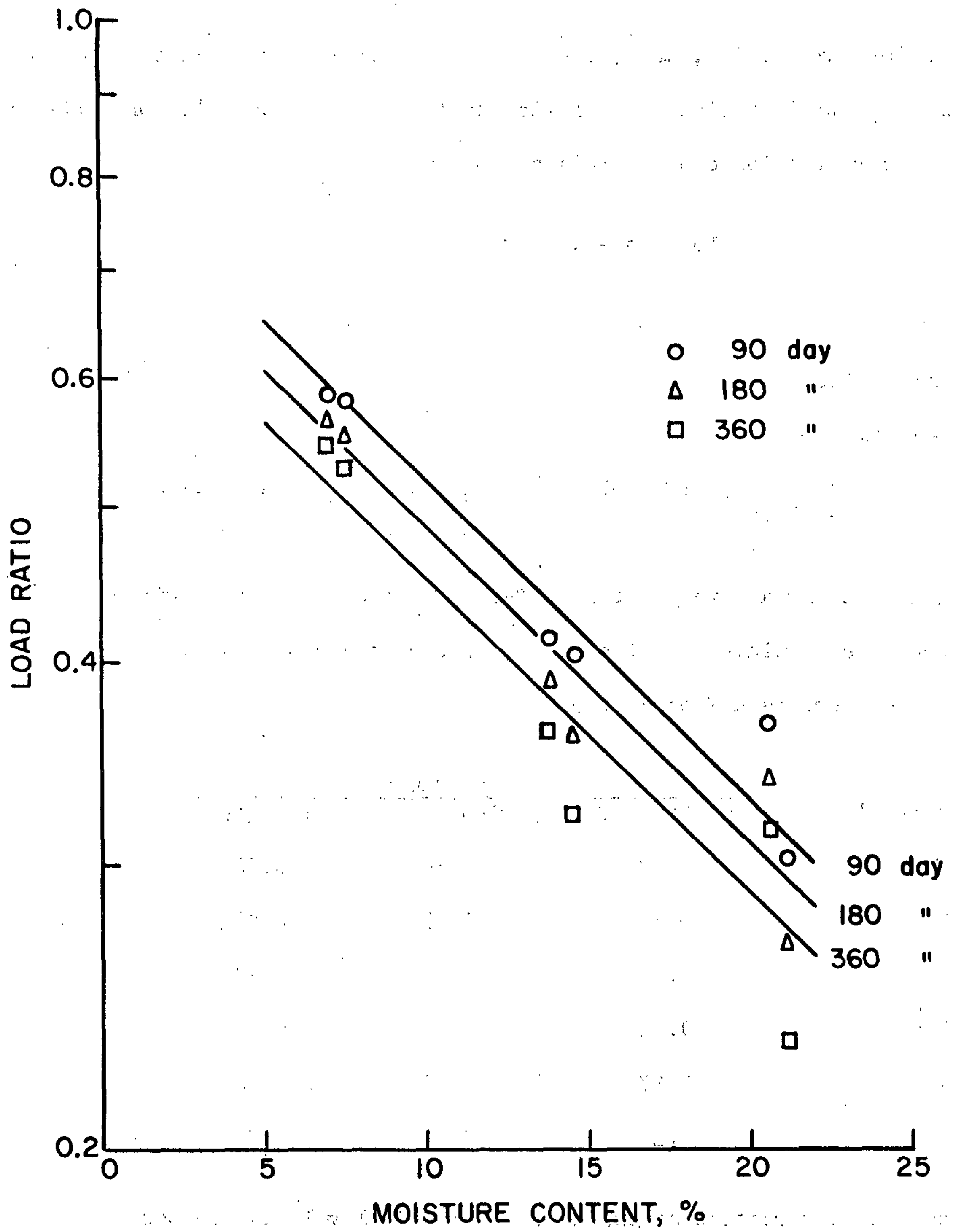

Figure 9. Load Ratio vs. Moisture Content Curves for Boxes

graphed in Fig. 10 and illustrate that the allowable load for a given survival time decreases very rapidly with increased moisture content. For this reason, overdesign of a package to meet environmental conditions which are rarely encountered can be costly.

It should be noted that the boxes for this study were made with regular starch adhesive. It was observed that at 90% R.H., 90°F. there was a tendency for the adhesion to fail as the exposure times increased. This probably would not occur if weather-resistant adhesive were used and, hence, moisture content might have a somewhat lesser effect on the load-carrying capacity of weather-resistant board.

The 180-day results in Fig. 10 are near the 200-day results obtained by Stott (3) but at a lower level. For example, at 20% moisture, Stott reported that the load carrying capacity would be about 13-14%, whereas in Fig. 10 the corresponding result was about 11%. At 10% moisture, Stott reported a 200-day survival time of about 53-54%, whereas in Fig. 10 the load carrying capacity was about 40%. Thus, Stott's results decline more rapidly with increased moisture content than did the results for the boxes of this study.

The values in Table VI were read from Fig. 10:

TABLE VI

EFFECT OF MOISTURE CONTENT ON STACKING LOAD

Moisture, % o.d.	Load in % of Strength at Standard Conditions		
	90-Day Life	180-Day Life	360-Day Life
7.5	60	55	51
10.0	43	40	37
12.5	32	29	27
15.0	23	21	20
17.5	16	15	14
20.0	12	11	11

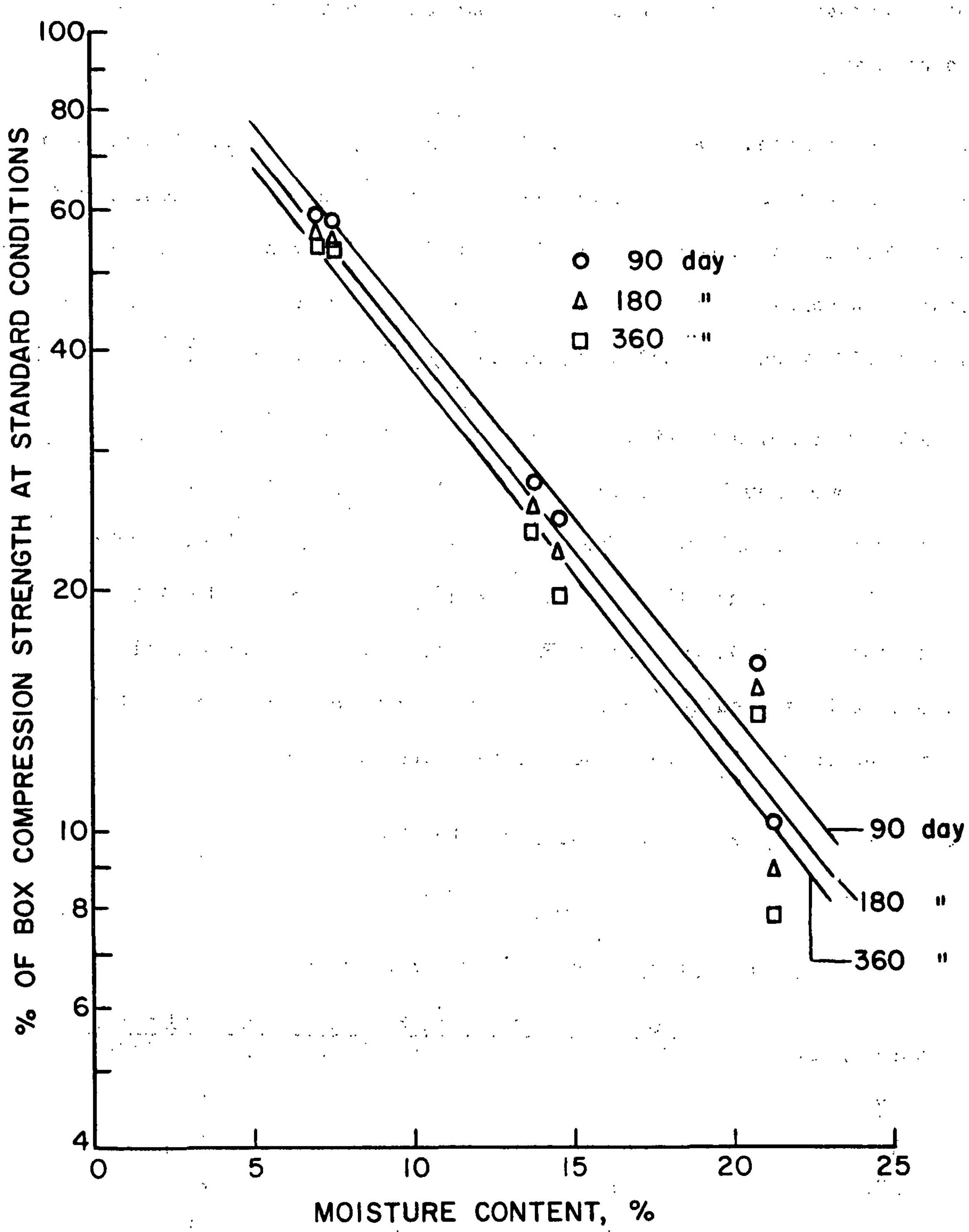

Figure 10. Load in Percentage of Compression Strength at Standard Conditions *vs*. Moisture Content

In Fig. 10 parallel regression lines were fitted to the Data. The regression equation was as follows:

$$\text{Log } L = \text{Log } 100\ (P/P_o) = -0.0504m + k \qquad (2)$$

where

Log $\underline{L}$ = applied load ($\underline{P}$) in percent of box compression strength at standard conditions ($\underline{P}_o$)

$\underline{m}$ = moisture content, % o.d.

$\underline{k}$ = +2.14132 for 90-day storage life

= +2.10892 for 180-day storage life

= +2.07335 for 360-day storage life

It is well known that the effect of moisture content on the maximum short-term compression strength can be approximately described by an exponential equation which is essentially similar in form to Equation (2). For example, for the box compression vs. moisture relationship, Kellicutt and Landt (1) reported a slope value of -3.01 using moisture content expressed as a fraction. If moisture content is expressed in percentage, their slope value would equal -0.0301. It may be noted that the stacking slope value in Equation (2) is 1.67 times greater than the box compression slope value. Thus, the allowable stacking loads for the boxes of this study decreased with increased moisture content at a faster rate than occurs in the case of short-term box compression strength.

STACKING RESULTS ON STACKED BOXES

The stacking test results on the stacked boxes from Sample C-200 are tabulated in Tables VII-IX for 50% R.H., 73°F., 85% R.H., 73°F., and 90% R.H., 90°F., respectively. For each applied load level the tables show the times required for the central stack deflection to attain 90, 95, and 100% of the

TABLE VII

TEST RESULTS ON STACKED C-200 BOXES AT 50% R.H., 73°F.

Applied Load, lb.	Load per Box,[b] lb.	Test No.	Deflection End Point, %: 100% Defl. (1.53 in., 1824 lb.)[a] R	100% Defl. t, day	95% Defl. (1.45 in., 1780 lb.)[a] R	95% Defl. t, day	90% Defl. (1.38 in., 1730 lb.)[a] R	90% Defl. t, day
1569	314	1	0.860	1.0	0.881	0.17	--	--
1569	314	2	0.860	2.8	0.881	0.55	--	--
Av.			0.860	1.9	0.881	0.36	--	--
1423	285	1	0.780	16.0	0.799	7.2	0.823	2.6
1423	285	2	0.780	21.0	0.799	7.0	0.823	1.4
Av.			0.780	18.5	0.799	7.1	0.823	2.0
1350	270	1	0.740	42.0	0.758	15.0	0.780	7.0
1350	270	2	0.740	30.0	0.758	8.4	0.780	2.8
Av.			0.740	36.0	0.758	11.7	0.780	4.9
1277	255	1	0.700	56.0	0.717	48.0	0.738	34.0
1277	255	2	0.700	60.0	0.717	52.0	0.738	48.0
Av.			0.700	58.0	0.717	50.0	0.738	41.0

[a] The first figure is the stack deflection at the indicated percentage deflection end point. The second figure is the average short-term compression load of the stacked boxes at the indicated deflection.

[b] Applied load divided by number of boxes per tier (5).

Note: R is the load ratio, i.e., applied load divided by short-term compression strength at specified deflection level. t is the time required to attain the indicated deflection level.

TABLE VIII

TEST RESULTS ON STACKED C-200 BOXES AT 85% R.H., 73°F.

Applied Load, lb.	Load per Box,[b] lb.	Test No.	Deflection End Point, % 100% Defl. (1.38 in., 1283 lb.)[a] R	t, day	95% Defl. (1.31 in., 1220 lb.)[a] R	t, day	90% Defl. (1.24 in., 1170 lb.)[a] R	t, day
1001	200	1	0.780	1.6	0.820	0.78	0.856	0.34
1001	200	2	0.780	2.1	0.820	1.00	0.856	0.40
Av.			0.780	1.8	0.820	0.89	0.856	0.37
898	180	1	0.700	3.0	0.736	1.6	0.768	0.70
898	180	2	0.700	3.8	0.736	2.8	0.768	1.90
Av.			0.700	3.4	0.736	2.2	0.768	1.30
795	159	1	0.620	21.0	0.652	14.5	0.679	8.8
795	159	2	0.620	9.6	0.652	5.0	0.679	2.6
Av.			0.620	15.3	0.652	9.8	0.679	5.7
744	149	1	0.580	50.0	0.610	33.0	0.636	19.0
744	149	2	0.580	34.0	0.610	17.0	0.636	10.0
Av.			0.580	42.0	0.610	25.0	0.636	14.5

[a] The first figure is the stack deflection at the indicated percentage deflection end point. The second figure is the average short-term compression load of the stacked boxes at the indicated deflection.

[b] Applied load divided by number of boxes per tier (5).

Note: R is the load ratio, i.e., applied load divided by short-term compression strength at specified deflection level. t is the time required to attain the indicated deflection level.

TABLE IX

TEST RESULTS ON STACKED C-200 BOXES AT 90% R.H., 90°F.

Applied Load, lb.	Load per Box,[b] lb.	Test No.	Deflection End Point, %: 100% Defl. (0.76 in., 581 lb.)[a] R	t, day	95% Defl. (0.72 in., 550 lb.)[a] R	t, day	90% Defl. (0.68 in., 520 lb.)[a] R	t, day
360	72	1	0.620	0.80	0.655	0.50	0.692	0.30
360	72	2	0.620	2.20	0.655	1.20	0.692	0.82
Av.			0.620	1.50	0.655	0.85	0.692	0.56
337	67	1	0.580	4.0	0.613	2.8	0.648	1.5
337	67	2	0.580	7.0	0.613	6.0	0.648	3.7
Av.			0.580	5.5	0.613	4.4	0.648	2.6
279	56	1	0.480	33.0	0.507	32.0	0.537	30.0
279	56	2	0.480	29.0	0.507	22.0	0.537	11.6
Av.			0.480	31.0	0.507	27.0	0.537	20.8

[a] The first figure is the stack deflection at the indicated percentage deflection end point. The second figure is the average short-term compression load of the stacked boxes at the indicated deflection.

[b] Applied load divided by number of boxes per tier (5).

Note: R is the load ratio, i.e., applied load divided by short-term compression strength at specified deflection level. t is the time required to attain the indicated deflection level.

deflection at maximum load in the short-term compression test of the stacked boxes. For example, at standard conditions the average deflection of the stacked boxes at maximum load in the short-term test was 1.53 inches. This is termed the 100% deflection end point in Table VII. The 95 and 90% deflection end points correspond to 1.45 and 1.38 stack deflections, respectively. Thus, Table VII shows the times required to attain these three deflection end points for each test. These deflection levels were referenced to 250 lb. (5 boxes per tier x 50 lb.) as zero deflection so that they would be comparable to deflections for single boxes where a 50-lb. preload is specified.

It is necessary to define "failure" in this way because the stacked boxes do not normally exhibit a catastrophic failure such as is obtained when individual boxes are tested. In the latter case, failure is usually manifested by a sudden drop of the weights. Thus, failure must be defined somewhat differently in the case of stacked boxes and deflection is a convenient and useful end point because excessive deflections can result in product damage or toppling stacks.

The load ratio vs. times to attain the stated deflections are graphed in Fig. 11. As in the case of the individually tested boxes, the regression lines for the three atmospheres were at markedly different levels. Thus, at a given load ratio the times markedly increase as the test atmosphere is changed from 90% R.H., 90°F. to 85% R.H., 73°F. to 50% R.H., 73°F. An analysis of covariance indicated that the differences in level of the regression lines due to test atmosphere were highly significant (0.01 level). The same result was obtained previously for the individually tested boxes.

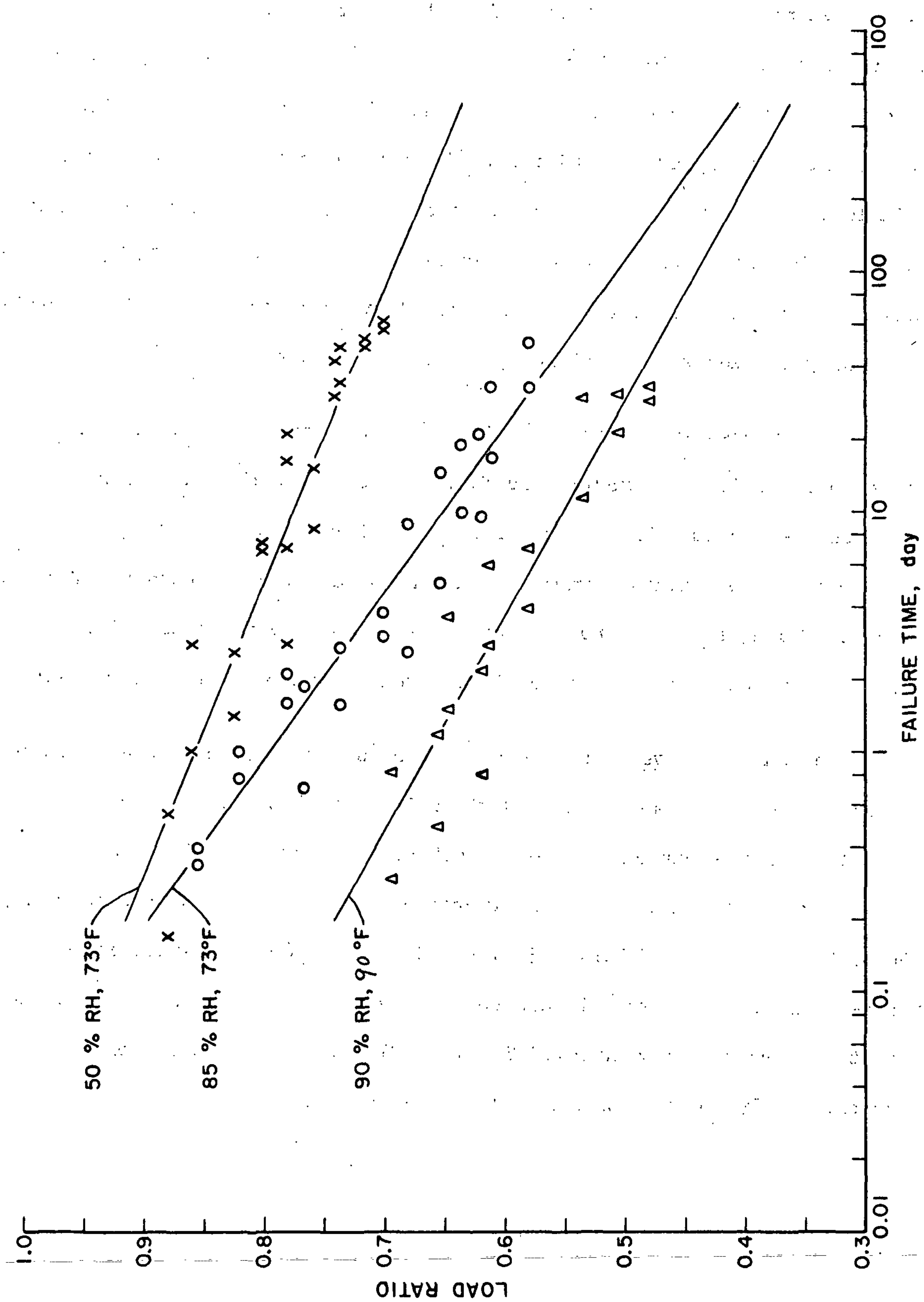

Figure 11. Load Ratio vs. Failure Time for Stacked Boxes

Thus, the results show that moisture content had a greater effect on the stacking behavior of the stacked boxes than it had on the compression strength of the stacked boxes.

The regression constants for the regression lines illustrated in Fig. 11 are tabulated in Table X. The slopes of the log t vs. R relationships in the three atmospheres were significantly different at the 0.01 level. This indicates that it would be questionable to fit parallel lines to the data in this instance. As mentioned previously, the high variability of creep data results in fairly large confidence limits on the regression coefficients. Hence, a considerable amount of data would be required to establish how the slope actually varies as the moisture content is changed.

Figure 12 compares the load ratio vs. log time regression lines for the stacking tests on (a) individually tested boxes and (b) stacked boxes. There is danger in drawing any broad conclusions from one comparison of this type, however, in each atmosphere and in the time region of interest the regression line for the stacked boxes is displaced vertically upward from the regression line for the individual boxes. This means that for a given storage time the stacked boxes sustained a load which is a higher percentage of their short-term compression strength than did the individually tested boxes. There appears to be no entirely satisfactory explanation for this difference in behavior. More work in this area would be of interest.

Table X also shows the predicted load ratios for 90, 180, and 360-day stacking periods. At 50% R.H. and 73°F., the predicted load ratios were 0.697, 0.672, and 0.648 for 90, 180, and 360-day stacking periods. At 85% R.H., 73°F. the predicted load ratios were 0.513, 0.469, and 0.426 and at 90% R.H., 90°F.

TABLE X

REGRESSION CONSTANTS FOR RELATIONSHIPS BETWEEN LOAD RATIO AND FAILURE TIME FOR STACKED BOXES

Conditions		Moisture Content,	No. of Data	Slope,	Intercept,	Corr.	Predicted Load Ratio		
R.H., %	Temp., °F.	%	Points	b[a]	Log a	Coeff.	90-Day	180-Day	360-Day
50	73	7.5	22	-12.19	10.4494	-0.94	0.697	0.672	0.648
85	73	13.8	24	-6.94	5.5141	-0.96	0.513	0.469	0.426
90	90	21.2	18	-8.95	5.9246	-0.93	0.444	0.410	0.376

[a] Differences in slope were significant at the 0.01 level.

Note: Regression equation form: Log $t = a + bR$, where t is time in days, R is the load ratio, and a, b are regression constants.

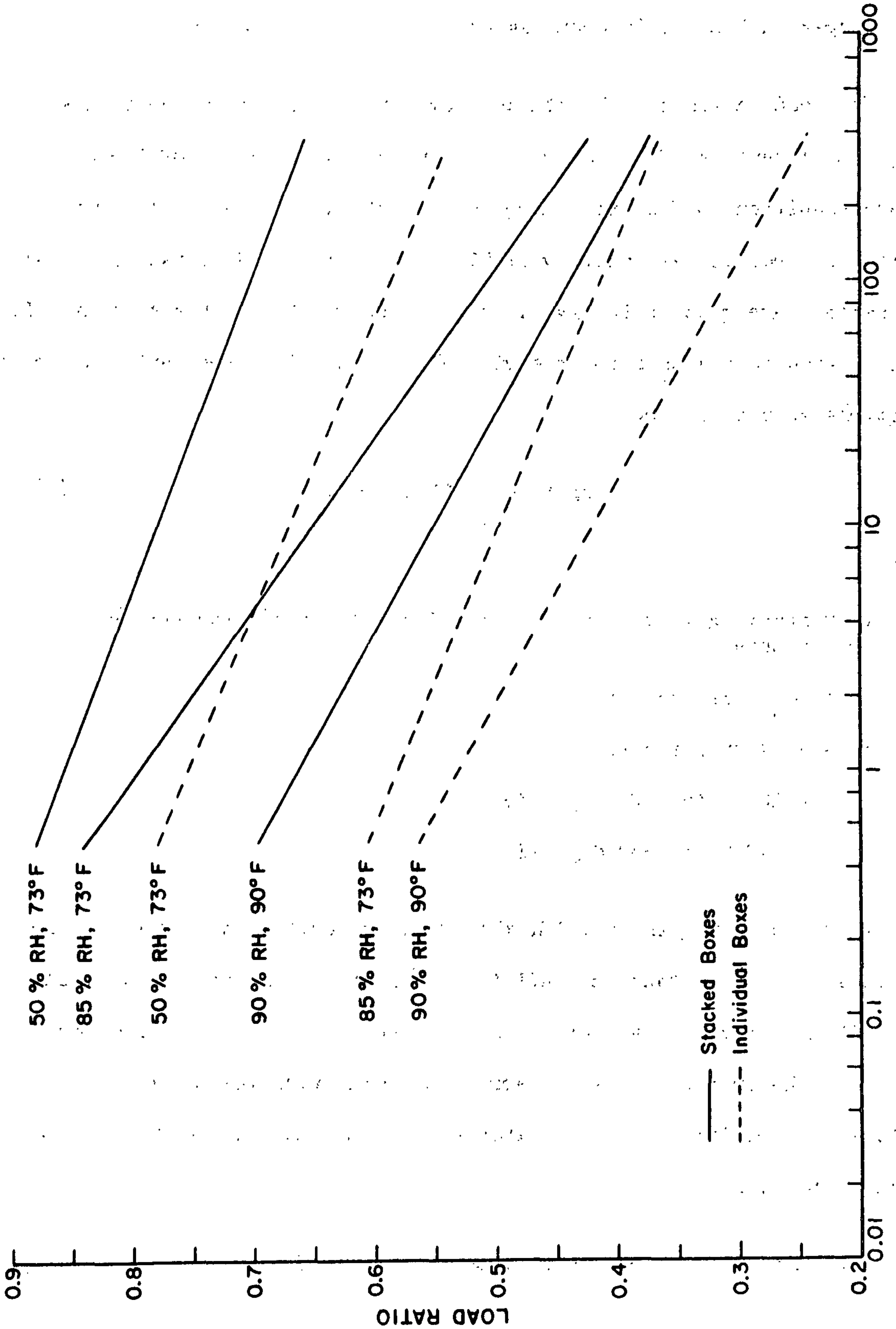

Figure 12. Comparison of Stacking Regression Lines for Stacked and Individual Sample C-200 Boxes

the corresponding load ratios were 0.444, 0.410, and 0.376. Thus, fairly substantial changes in load ratio occur as moisture content changes.

The load ratios for the stacked boxes were also converted to loads expressed in terms of a percentage of the short-term compression strength of the stacked boxes at standard conditions. This is a more convenient way to express the results when compression test results are only available at standard conditions. The stacking loads in percent are graphed in Fig. 13 as a function of moisture content. Parallel lines were fitted to the data for the 90, 180, and 360-day time periods. The regression equations were as follows:

$$\text{Log } L_s = -0.05168m + k \tag{3}$$

where

$\underline{L_s}$ = stacking load in percentage of stack compression strength at standard conditions

$\underline{m}$ = moisture content, % o.d.

$\underline{k}$ = 2.24685 for 90-day life

= 2.10892 for 180-day life

= 2.07335 for 360-day life

As may be noted in Fig. 13, the stacking load in percentage of the compression strength at standard conditions decreased with increasing moisture content at about the same rate for the stacked boxes as for the individually tested boxes. The curves are offset somewhat, reflecting the tendency of the stacked boxes to survive for longer times at the same load ratio as compared to the individual boxes.

The values in Table XI were read from Fig. 13.

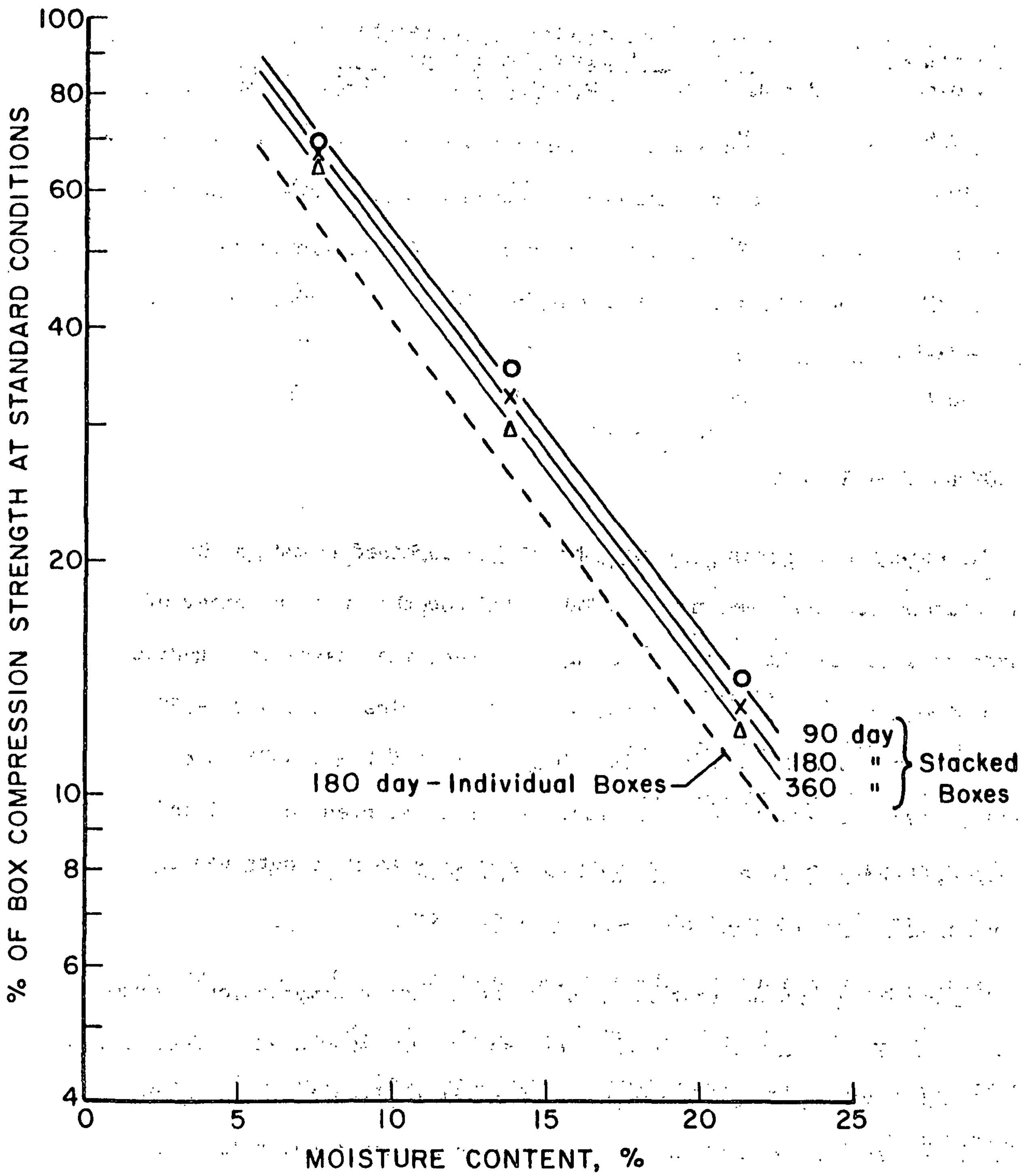

Figure 13. Load in Percentage of Compression Strength at Standard Conditions vs. Moisture Content for Stacked Boxes

TABLE XI

EFFECT OF MOISTURE CONTENT ON STACKING
LOAD OF STACKED BOXES

Moisture,	Load in Percentage of Strength at Standard Conditions		
% o.d.	90-Day Life	180-Day Life	360-Day Life
7.5	72	67	64
10.0	53	50	47
12.5	39	37	35
15.0	29	27	26
17.5	22	20	19
20.0	16	15	14

EDGEWISE COMPRESSION RESULTS

The edgewise compression strengths of the combined board in the three test atmospheres are summarized in Table XII together with a number of other characteristics of the boards. As may be noted, the losses in edgewise compression strength amounted to 42.4 and 43.7% for Samples C-200 and C-350, respectively, in the 85% R.H., 73°F. atmospheres. At 90% R.H., 90°F. the corresponding losses in edgewise compression strength amounted to -56.0 and -53.0%. These changes were about the same in magnitude as were obtained in the case of the top load compression tests on the boxes.

The stacking (creep) test results on the edgewise compression specimens are summarized in Table XIII and the detailed results are tabulated in Appendix I. Reference to Table XIII or Fig. 14 indicates that, at a given load ratio, the failure times markedly increased as the test atmosphere was changed from 90% R.H., 90°F. to 85% R.H., 73°F. to 50% R.H., 73°F. For example, for Sample C-200

TABLE XII

COMBINED BOARD TEST RESULTS

Test	50% R.H., 73°F.	85% R.H., 73°F.	Diff., %	90% R.H., 90°F.	Diff., %
Sample C-200					
Basis weight, lb./M ft.^{2}	124	--	--	--	--
Caliper, pt.	159	161	+1.3	162	+1.9
Edgewise compression, lb./in.[a]	43.6	25.1	-42.4	19.2	-56.0
Pin adhesion, lb.	50	30	-40.0	27	-46.0
Flexural stiffness, lb.-in. M.D.	127	--	--	--	--
C.D.	47	--	--	--	--
Sample C-350					
Basis weight, lb./M ft.^{2}	215	--	--	--	--
Caliper, pt.	177	182	+2.8	185	+4.5
Edgewise compression, lb./in.[a]	75.5	42.5	-43.7	35.5	-53.0
Pin adhesion, lb.	52	34	-34.6	30	-42.3
Flexural stiffness, lb.-in. M.D.	360	--	--	--	--
C.D.	128	--	--	--	--

[a] 2 x 2 x 1.25 in. tubular specimen with wax dipped edges.

TABLE XIII

SUMMARY OF COMBINED BOARD EDGEWISE COMPRESSION CREEP TEST RESULTS

Load Ratio[a]	Sample C-200						Sample C-350					
	50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.		50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.	
	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day
0.74							55.86	0.63				
0.70							52.84	2.04				
0.66	28.81	0.49	16.55	0.43			49.82	6.61	28.07	0.378		
0.62	27.06	2.57	--	--			46.80	15.1	26.36	3.13		
0.58	25.32	4.13	14.54	2.00					24.66	4.30		
0.54	23.57	34.4	--	--	10.37	0.04			22.96	13.19	19.15[b]	
0.50			12.54	23.0	--	--					17.73	0.168
0.46			--	--	8.83	0.56					--	--
0.42			10.53	49.5	8.06	9.64					14.89	7.48
0.38					--	--					--	--
0.34					--	--					12.06	38.5
0.30					5.76	27.5					--	--

[a]Ratio of applied load to short-term compression strength in the test atmosphere.

[b]Failure times were less than 0.01 day.

Note: P_a is the applied load and t is the failure time.

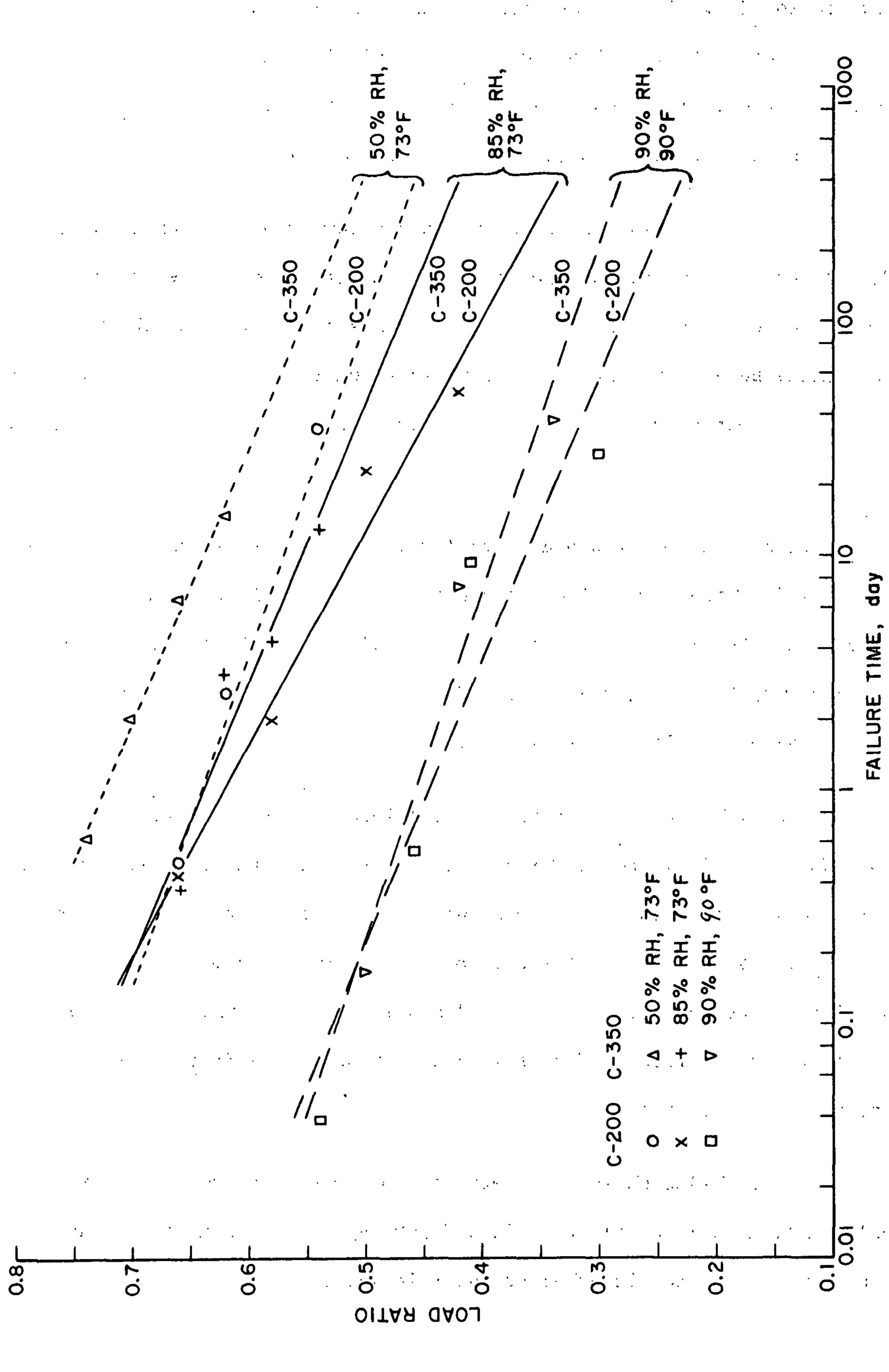

Figure 14. Load Ratio vs. Failure Time Curves for Combined Board Edgewise Compression

at a load ratio of 0.5 the average failure times were about 0.23, 13, and 100 days in the 90, 85, and 50% R.H. atmospheres, respectively. An analysis of covariance indicated that the differences in level of the regression lines in the three atmospheres were highly significant (beyond the 0.01 level).

Thus, the edgewise compression creep behavior of the combined board was affected by the test atmosphere, i.e., by increasing moisture content, in the same manner as box stacking behavior. This similarity in behavior would certainly be expected inasmuch as it is known that box compression strength is very dependent on the edgewise compression strength of the combined board.

Because the load ratio adjusts for the short-term strength, the decrease in level of the regression lines with increased moisture content indicates that creep behavior is more affected by moisture content than is the short-term strength. Thus, the results for both the boxes and columns are in agreement with Stott's (3) results for boxes.

Table XIV shows the regression coefficients for the lines graphed in Fig. 14. While fairly large differences in slope were obtained, the analysis of covariance indicated that the slopes were not significantly different at the 0.05 level. Therefore, in the case of these edgewise compression results, the individual least squares regression lines in Fig. 14 could be replaced by a family of parallel lines if desired. The regression coefficients for this case are also shown in Table XIV.

Table XIV also shows the predicted load ratios corresponding to extrapolated failure times of 90, 180, and 360 days. The results for the two samples were averaged together as shown in Table XV.

TABLE XIV

REGRESSION CONSTANTS FOR EDGEWISE COMPRESSION CREEP RESULTS

Sample No.	Conditions		Individual Regression Lines						Parallel Line Fit				
	R.H., %	Temp., °F.	Slope, b[a]	Intercept, Log a	Corr. Coeff.	Predicted Load Ratio 90-Day	180-Day	360-Day	Slope, b[a]	Intercept, Log a	Predicted Load Ratio 90-Day	180-Day	360-Day
C-200	50	73	-14.36	9.1816	0.975	0.503	0.482	0.461	-11.54	7.4865	0.479	0.453	0.427
	85	73	-9.05	5.6369	0.983	0.407	0.373	0.340	-11.54	6.9784	0.435	0.409	0.383
	90	90	-11.94	5.3286	0.934	0.283	0.257	0.232	-11.54	5.1551	0.277	0.251	0.225
C-350	50	73	-11.62	8.4285	0.997	0.557	0.531	0.505	-11.54	8.3732	0.556	0.530	0.504
	85	73	-11.91	7.6056	0.955	0.474	0.449	0.424	-11.54	7.3799	0.470	0.444	0.418
	90	90	-14.75	6.7573	0.975	0.326	0.305	0.285	-11.54	5.4079	0.299	0.273	0.247

[a]Slopes were not significantly different at the 0.05 level.

Note: Regression equation form: Log $t = a + bR$, where t is the failure time in days, R is the load ratio, and a, b are regression constants.

TABLE XV

AVERAGE EDGEWISE COMPRESSION LOAD RATIOS

Condition	Average Load Ratio		
	90-Day Life	180-Day Life	360-Day Life
50% R.H., 73°F.	0.530	0.506	0.483
85% R.H., 73°F.	0.440	0.411	0.382
90% R.H., 90°F.	0.304	0.281	0.258

Thus, the average load ratios corresponding to a 180-day storage period were 0.506, 0.411, and 0.281 in the 50, 85, and 90% R.H. atmospheres. These decreases are very substantial, particularly when it is kept in mind that edgewise compression strength also decreases markedly with increased moisture content. On the average, at 50% R.H. the edgewise compression load supported for 180 days would be 22.1 lb./in. (0.506 x 43.65 lb./in.) for Sample C-200. The corresponding result would be 5.4 lb./in. (0.281 x 19.20 lb./in.) at 90% R.H., 90°F. for Sample C-200. This is a loss in load-carrying capacity of 76%, whereas the loss in edgewise compression strength was only 56%.

The average load ratios in Table XV are roughly about the same in magnitude as were obtained for the individual boxes. They were lower in magnitude than the load ratios obtained for the stacked boxes.

The load ratios were converted to edgewise compression loads expressed in terms of edgewise compression at standard conditions. The resulting values are plotted in Fig. 15 as a function of moisture content. Figure 15 shows that the applied creep load (referenced to standard conditions) for edgewise compression decreases with increased moisture content in the same way as the box results. The regression equations for the parallel lines shown in Fig. 15 were as follows:

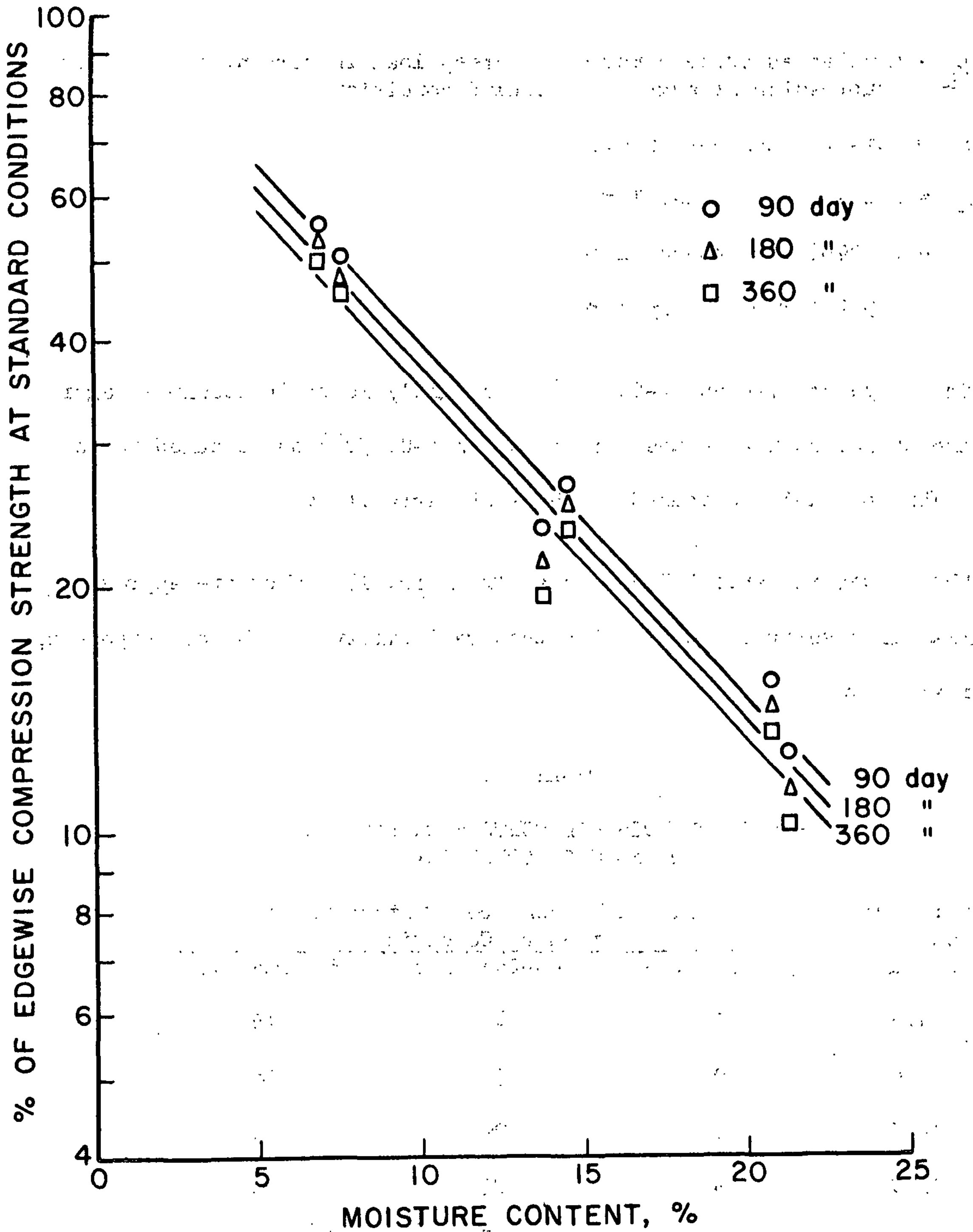

Figure 15. Load in Percentage of Compression Strength at Standard Conditions *vs*. Moisture Content for Edgewise Compression Creep Results

$$\text{Log } L_c = -0.0437m + k \qquad (4)$$

where

$\underline{L_c}$ = applied edgewise compression creep load in percent of edgewise compression strength at standard conditions

$\underline{m}$ = moisture content, % o.d.

$\underline{k}$ = 2.03797 for 90-day life

= 2.00986 for 180-day life

= 1.97961 for 360-day life

The slope coefficient (-0.0437) is slightly lower in absolute magnitude than the corresponding values for the boxes (-0.0504) and stacked boxes (-0.0517). This probably is caused by the test variability.

The values in Table XVI were read from Fig. 15. They are approximately similar in magnitude, considering test variability, to the corresponding results for the boxes.

TABLE XVI

EFFECT OF MOISTURE CONTENT ON EDGEWISE COMPRESSION CREEP LOAD

Moisture Content, % o.d.	Load in Percentage of Strength at Standard Conditions		
	90-Day Life	180-Day Life	360-Day Life
7.5	51	48	45
10.0	40	37	35
12.5	31	29	27
15.0	24	23	21
17.5	19	18	17
20.0	15	14	13

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APPENDIX I

TEST RESULTS FOR BOXES AND EDGEWISE COMPRESSION TESTS

TABLE XVII

BOX STACKING LIVES

Load Ratio	Spec. No.	C-200 50% R.H., 73°F. P_a, lb.	t, day	C-200 85% R.H., 73°F. P_a, lb.	t, day	C-200 90% R.H., 90°F. P_a, lb.	t, day	C-350 50% R.H., 73°F. P_a, lb.	t, day	C-350 85% R.H., 73°F. P_a, lb.	t, day	C-350 90% R.H., 90°F. P_a, lb.	t, day
0.74	1	639	1.11	419	0.011			993	0.13	610	0.182		
	2	639	1.94	419	0.037			993	1.08	610	0.024		
	3	639	2.67	419	0.003			993	0.54	610	0.222		
	4	639	1.12	419	0.001			993	0.81	610	0.064		
	Av.	639	1.71	419	0.013			993	0.64	610	0.123		
0.70	1	605	6.88	396	0.016			939	1.60	577	0.264		
	2	605	4.59	396	0.007			939	4.24	577	0.013		
	3	605	0.25	396	0.035			939	1.73	577	1.632		
	4	605	0.55	396	0.028			939	4.48	577	1.271		
	Av.	605	3.07	396	0.022			939	3.01	577	0.80		
0.66	1	570	21.09	374	0.417			886	5.43	544	0.56		
	2	570	16.65	374	0.158			886	4.11	544	2.28		
	3	570	4.66	374	0.057			886	5.47	544	1.66		
	4	570	4.07	374	0.063			886	9.53	544	0.16		
	Av.	570	11.62	374	0.174			886	6.14	544	1.16		
0.62	1	536	7.66	351	0.90			832	12.90	511	4.44		
	2	536	43.45	351	0.60			832	46.29	511	4.42		
	3	536	51.58	351	0.20			832	41.88	511	7.88		
	4	536	42.66	351	0.15			832	53.65	511	1.92		
	Av.	536	36.34	351	0.46			832	38.68	511	4.66		
0.54	1			306	1.46	156	0.19			445	2.59	320	0.57
	2			306	3.46	156	1.14			445	1.44	320	0.64
	3			306	3.25	156	1.44			445	12.64	320	0.91
	4			306	4.13	156	0.63			445	12.47	320	0.16
	Av.			306	3.08	156	0.85			445	7.28	320	0.57
0.50	1			283	6.02					412	2.61	296	3.64
	2			283	8.77					412	36.88	296	9.23
	3			283	10.42					412	14.47	296	0.45
	4			283	16.64					412	25.66	296	1.33
	Av.			283	10.46					412	19.90	296	3.66
0.42	1			238	62.58	121	2.43			346	95.66	249	3.85
	2			238	94.78	121	3.84			346	40.40	249	31.05
	3			238	45.83	121	11.52			346	21.99	249	21.44
	4			238	39.48	121	16.07			346	29.14	249	15.86
	Av.			238	60.67	121	8.46			346	46.80	249	18.05
0.38	1					110	20.98						
	2					110	20.74						
	3					110	20.74						
	4					110	19.96						
	Av.					110	20.60						

Note: P_a is the applied load and t is the failure time.

TABLE XVIII

EDGEWISE COMPRESSION STACKING LIVES

		C-200						C-350					
		50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.		50% R.H., 73°F.		85% R.H., 73°F.		90% R.H., 90°F.	
Load Ratio	Spec. No.	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day	P_a, lb./in.	t, day
0.74	1								0.27				
	2								0.48				
	3								1.70				
	4								0.06				
	Av.							55.86	0.63				
0.70	1								4.52				
	2								0.06				
	3								1.37				
	4								2.21				
	Av.							52.84	2.04				
0.66	1		0.139		0.61				9.53		0.455		
	2		0.361		0.32				6.65		0.099		
	3		0.118		0.24				6.34		0.941		
	4		1.344		0.54				3.91		0.019		
	Av.	28.81	0.490	16.55	0.43			49.82	6.61	28.07	0.378		
0.62	1		2.89						4.48		1.45		
	2		2.46						5.14		1.10		
	3		2.03						13.78		2.57		
	4		2.91						36.94		7.41		
	Av.	27.06	2.57					46.80	15.08	26.36	3.13		
0.58	1		3.47		2.48						3.90		
	2		3.64		2.80						8.26		
	3		3.97		1.57						3.78		
	4		5.43		1.13						1.28		
	Av.	25.32	4.13	14.54	2.00					24.66	4.30		
0.54	1		45.84				0.111				12.08		
	2		14.73				0.014				23.52		
	3		38.48				0.003				12.58		
	4		38.65				0.032				4.59		
	Av.	23.57	34.42			10.37	0.040			22.96	13.19		
0.50	1				48.93								0.110
	2				18.54								0.231
	3				12.82								0.188
	4				11.47								0.144
	Av.			12.54	22.94							17.73	0.168
0.46	1						1.594						
	2						0.126						
	3						0.431						
	4						0.087						
	Av.					8.83	0.560						
0.42	1				68.58		5.66						0.31
	2				44.46		10.60						9.63
	3				40.57		12.39						15.38
	4				44.50		9.92						4.61
	Av.			10.53	49.53	8.06	9.64					14.89	7.48
0.30/ 0.34	1						18.67						35.59
	2						21.95						22.46
	3						35.66						91.59
	4						33.74						4.44
	Av.					5.76	27.50					12.06	38.52

ERRATUM

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Page 3, Line 11.

Please change this sentence to read as follows:

For this reason overdesign of a package to meet environmental conditions which are rarely encountered can be costly and conversely, when extreme moisture conditions are encountered, greater stacking safety factors may be required than would be expected on the basis of top load compression strength behavior.